Analytical Results, Findings, and Recommendations of the 1995 OMAF Sewage Biosolids Field Survey

Prepared by the
Sewage Biosolids Survey Team

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Analytical Results, Findings, and Recommendations of the 1995 OMAF Sewage Biosolids Field Survey

Preface

The 1995 OMAF Sewage Biosolids Field Survey was undertaken to study pH, phosphorus and metal levels in selected agricultural soils which had received multiple applications of sewage biosolids. The survey was carried out in response to a number of concerns regarding the application of sewage biosolids on agricultural lands in Ontario, namely:

- Field-level monitoring of nutrient and metal levels in agricultural soils which had received applications of sewage biosolids had not been carried out by the OMAF on a broad basis across Ontario.
- The lack of monitoring efforts had resulted in limited supporting documentation of the provincial guidelines for the utilization of sewage biosolids on agricultural land, first approved for implementation by the Ontario Cabinet in 1979, and revised in 1986 and 1992.
- The absence of supporting documentation of the guidelines had led to persistent health and safety concerns within the urban and rural communities of the province.

The terms "metals" and "heavy metals" are a source of confusion in published reports and scientific papers. Arsenic and selenium are commonly referred to a metals or heavy metals, when in fact they are non-metal elements. However, like many metals or heavy metals, they can be toxic to plants, animals, or humans at high concentrations.

Since arsenic and selenium are referred to as metals in the current Guidelines for Sewage Sludge Utilization on Agricultural Lands (MOEE/OMAF, 1992), they are also referred to as metals in this report. The authors are aware of this confusion, and hope that in the future there will be steps taken to clarify the terms "metals" and "heavy metals" and the elements which they represent.

This report was first printed in December, 1995, and reprinted in April, 1996. The reprinted version described herein includes some minor revisions made to the original report, including: 1) the correction of minor typographical errors; 2) the use of the term "method detection limit" rather than "minimum detection limit"; and 3) the revision of the method detection limit for molybdenum - the limit should have been 2.5 ppm, rather than 0.5 ppm. These changes do not affect the original findings and recommendations, with one exception. The revised method detection limit for molybdenum is greater than the mean molybdenum level in uncontaminated Ontario soils (2 ppm). Therefore, it can not be concluded as first reported that, for the non-treated soils, the number of years for molybdenum to reach its maximum permissible level would be greater than the number of years indicated in the guidelines.

As a cost saving measure, the appendix in the original report has been deleted from this reprinted version. The average pH, phosphorus and metal levels for individual field sites, which were given in the appendix, can be obtained from Tables 5, 6, and 7. The analytical results for individual soil samples taken at each site, also given in the appendix, are available on request.

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Analytical Results, Findings, and Recommendations of the 1995 OMAF Sewage Biosolids Field Survey

Executive Summary

The utilization of sewage biosolids on agricultural lands benefits farmers, municipalities, and society. The current *Guidelines for Sewage Sludge Utilization on Agricultural Lands* (MOEE/OMAF, 1992) have been developed to facilitate the recycling and use of sewage biosolids on agricultural land, while protecting the quality of food, the health of consumers and livestock, and the quality of the environment.

According to the current guidelines, the Ministry of the Environment and Energy (MOEE) and the Ministry of Agriculture, Food and Rural Affairs (OMAF) are jointly responsible for determining metal concentrations in soils, to verify the acceptability of sewage biosolids application sites. However, neither ministry have undertaken field-level studies on a broad basis across Ontario to: 1) monitor levels of critical parameters in agricultural soils which have received applications of sewage biosolids; and 2) verify the acceptability of agricultural fields which have received sewage biosolids for extended periods. The lack of monitoring and verification efforts has resulted in limited supporting documentation of the guidelines. The absence of such documentation has resulted in **considerable scepticism and persistent health and safety concerns** within the urban and rural communities of Ontario.

The 1995 OMAF Sewage Biosolids Field Survey was undertaken in recognition of the ministry's responsibility to monitor critical parameters in soils which have received applications of sewage biosolids. It was also undertaken in order to address the public concerns related to health and safety. A report outlining the findings and recommendations of the field survey follows.

Purpose and Objectives

The purpose of the field survey was to conduct a general benchmark study of pH, phosphorus and metal levels in selected agricultural soils which have received multiple applications of sewage biosolids, in order to provide documentation in support of the criteria for those parameters in the current guidelines. The specific objectives of the field survey were:

1. To determine pH, phosphorus and metal levels in agricultural soils which have received multiple applications of sewage biosolids;
2. To compare the pH, phosphorus and metal levels in the soils which have received applications of sewage biosolids, to background levels in adjacent or nearby agricultural soils which have never received applications of sewage biosolids and which have similar physical characteristics;
3. To determine the total amount (loading) of metals applied to the soils from applications of sewage biosolids;
4. To determine the rate of build-up, if any, of metals in the soils which have received applications of sewage biosolids;
5. To compare the findings to the permissible levels in the current guidelines; and
6. To report the findings and make recommendations to OMAF senior management.

Field Survey

Thirty-six paired sites were selected and sampled in the survey. Each site consisted of a "treated plot" located in an agricultural field which had received multiple applications of sewage biosolids, and a "non-treated plot" located in an adjacent or nearby agricultural field composed of similar soils, and which had never received sewage biosolids. A woodlot was also sampled at 12 of the 36 paired sites. Twenty-seven of the paired sites had received sewage biosolids under three separate MOEE approvals, and 9 paired

sites had received sewage biosolids under 2 separate MOEE approvals. There were a total of 41 farmer cooperators.

Soil samples (0-20 cm) were taken at varying intervals along three transects located in each of the treated, non-treated, and woodlot plots. The total number of transects in the treated, non-treated, and woodlot plots were 108, 108, and 36, respectively. Each composite transect sample was thoroughly mixed, and two smaller transect samples were taken for analysis purposes. A total of 252 transect samples were analyzed for soil pH and available phosphorus levels, and a similar number of transect samples were analyzed for soil metal levels.

Findings and Conclusions

The mean pH values over all 36 sites for the treated, non-treated, and woodlot soils were 7.1, 7.2 and 6.4, respectively. Although slightly lower, the mean pH level in the treated soils was not significantly different from the pH level in the non-treated soils. These findings indicate that **the addition of sewage biosolids has not had a significant effect on soil pH**.

For the 12 sites where woodlot soils were also sampled, the mean pH values of the treated, non-treated and woodlot soils were 6.8, 6.9, and 6.4, respectively. None of the means were significantly different. These findings indicate that, for those sites, **agricultural use has not had a significant effect on soil pH**.

Seven of the 108 transect samples taken in the treated plots had available phosphorus levels greater than the maximum permissible level of 60 ppm as specified in the current guidelines. Based on the analytical results for 32 sites, the mean phosphorus levels for the treated and non-treated soils were 29.2 and 9.4 ppm, respectively. Statistical analysis indicated that available phosphorus in the treated soils was significantly elevated, but the resulting level in the treated soil was well below the maximum permissible level.

These findings indicate that **excess phosphorus levels are not a concern** in soils which have received multiple applications of sewage biosolids. Also, **the application of sewage biosolids has had a significant positive effect on the available phosphorus levels in the soils**. It would appear from these findings that **municipal sewage biosolids are an excellent source of phosphorus**. It would also appear that through controlled application rates and crop utilization, **available soil phosphorus is being maintained at acceptable levels** in soils which have received applications of sewage biosolids.

Three of the 108 transect samples taken in the treated plots had 1 metal level which was higher than the maximum permissible level as specified in the current guidelines. However, when the three levels for the transect samples were averaged, the soils in only 1 of the 36 treated plots had an average metal level which exceeded the maximum permissible level. For that plot, the abnormally high level was likely due to contamination at the time of sampling. For the other 35 treated plots, the average levels for the 11 metals were all lower than the maximum permissible levels.

The soils in 31 of the 36 treated plots had at least 1 average metal level which was lower than the maximum permissible level, but was higher than the average level in the soils in the comparison non-treated plot. Thirty-eight of 396 average levels determined for all metals in the treated soils exceeded 50% of the maximum permissible level. Twenty-three of those levels were higher than the average levels in the comparison non-treated soils.

The mean arsenic and zinc levels were lower in the treated soils than in the non-treated soils. Excluding molybdenum, the mean levels for the other 8 metals were all higher in the treated soils than in the non-treated soils. However, **only the mean levels of chromium, copper and mercury in the treated soils were found to be significantly different** from the mean levels for those elements in the non-treated soils. The mean levels of all metals in the treated soils were well below the maximum permissible level. Mean levels for molybdenum for both the treated and non-treated soils were not determined because the concentrations in all soil samples were below the method detection limit of 2.5 ppm.

These findings indicate that **excess metal levels are not a concern** in soils which have received multiple applications of sewage biosolids. The findings also indicate that, for the 36 sites included in the survey, **the applications of sewage biosolids have significantly elevated the chromium, copper and**

mercury contents in the soils, but the resulting levels are well below the maximum permissible levels.

The mean levels for cobalt, selenium and zinc for the non-treated soils were higher than the mean levels for those elements in uncontaminated Ontario soils, as reported in the current guidelines. However, the levels were equal to or lower than the mean levels for "Rural Parkland" as reported in the *Ontario Typical Range of Chemical Parameters in Soil, Vegetation, Moss Bags and Snow* (MOEE, 1993). Excluding molybdenum, the mean levels for the other 7 metals in the non-treated soils were lower than the mean levels for uncontaminated Ontario soils. A mean molybdenum level was not determined, but would be less than 2.5 ppm. The mean molybdenum level in uncontaminated Ontario soils is 2 ppm. These findings indicate that, excluding cobalt, molybdenum, selenium and zinc, **the number of years it would take for the other 7 metals to reach their maximum permissible level in the soils would be greater than the number of years reported in the current guidelines**.

Regarding the study objectives to determine metal loading and rates of build-up, there was insufficient data available for most of the sites to establish loading or possible rates of build-up for the 11 metals of concern. Sewage biosolids were first utilized on most sites prior to full implementation of the guidelines in 1982. Therefore, pre-application soil analysis information and records of sewage biosolids quality and application rates, were not available for many sites.

Recommendations

1. Monitoring of soil parameters which may be adversely affected by the application of sewage biosolids should be an on-going process.
2. Nutrient management plans should be established for all approved sewage biosolids utilization sites.
3. A more consistent and complete record keeping system needs to be established to facilitate future monitoring and verification of utilization sites.
4. There should be some further study of the analytical results included in this report, and of the loading and rates of build-up of phosphorus and metals in the soils included in the study.
5. There should be further study of the possibility of nutrient and metal stratification in soils receiving injected and non-incorporated sewage biosolids.
6. Analysis of soil organic matter and clay levels should also be undertaken in future monitoring or site verification studies of this type.

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Introduction

- Background
- Purpose and Objectives

Background

Municipal sewage treatment plants remove the solids in municipal sewage, and the treated water is discharged back into rivers and lakes. The solids left behind are treated aerobically or anaerobically to produce a by-product commonly referred to as stabilized sewage sludge. Stabilized sewage sludge that meets the current *Guidelines for Sewage Sludge Utilization on Agricultural Lands* (MOEE/OMAF, 1992), which outline the criteria and standards for application on agricultural land, is now defined as "biosolids" or "sewage biosolids". The latter term is used in this report. The term "current guidelines" is also used in this report, and refers to the 1992 guidelines document.

Sewage biosolids are the nutrient rich black residues remaining after sewage treatment. They are a valuable input into an agricultural cropping system because they contain nitrogen, phosphorus, some trace minerals, and organic matter, which are all beneficial additions to the soil. The utilization of sewage biosolids on agricultural land benefits farmers, municipalities and society in the following ways:

- it provides farmers with a low cost source of nitrogen (except for de-watered sewage biosolids), phosphorous, and certain micro-nutrients for crop production, reducing the need for commercial fertilizer;
- it supplies organic matter to the soil thereby improving its physical characteristics, including soil structure, water holding capacity and permeability;
- it supplies micro-organisms that enhance the soil biological population and activities, which results in increased levels of plant available nutrients in years subsequent to application;
- it provides municipalities with a cost-effective option to divert organic materials from sanitary landfill sites or incinerators. This extends the operating life of existing landfill sites, and reduces pressure to locate future sites on prime agricultural land; and
- it provides society with energy savings - less fuel is required to till soils and to manufacture commercial fertilizers.

However, there are also concerns related to the utilization of sewage biosolids on agricultural land. The general concerns are:

- odours;
- potential harmful affects of constituents on human, animal, and plant health (i.e. pathogens, metal toxicity);
- potential impairment of surface water quality by beneficial or harmful constituents (i.e. from surface run-off);
- potential impairment of groundwater quality by beneficial or harmful constituents (i.e. from leaching); and
- public perception.

The current guidelines were developed to facilitate the recycling and use of sewage biosolids on

agricultural land, while protecting the quality of food, the health of consumers and livestock, and the quality of the environment. The guidelines supplement Ontario Regulation 347, made under the *Environmental Protection Act*. They outline the criteria or standards which must be adhered to in order to utilize sewage biosolids on agricultural land. They also outline the responsibilities of the key stakeholders - the MOEE, the OMAF, the operating agencies, the haulers and applicators, and the farmers.

Sewage biosolids have been applied on agricultural lands in Ontario since the 1970's. Guidelines to control such applications were first developed in 1979, and fully implemented in 1982. Since that time, many soils have received multiple applications of sewage biosolids in accordance with the guidelines, and under approvals issued by the MOEE. Such applications should not result in excessive additions of nutrients or potentially harmful constituents to the soils.

The utilization of sewage biosolids on agricultural land may result in:

- excess phosphorus levels, which may potentially impair plant growth or water quality; and
- excess metal levels, which may potentially contribute to metal toxicity in humans, animals and plants due to potential accumulation in the soils, and subsequent uptake by plants and animals.

The addition of sewage biosolids to acidic soils with pH levels below 6.0, may potentially result in increased crop uptake of metals, and decreased availability of phosphorus and some micro-nutrients essential for plant growth. It is important, therefore, that the pH of soils receiving sewage biosolids be greater than 6.0.

The criteria for pH, phosphorus and metal levels in the current guidelines are supported by scientific research, ongoing since 1971. A research study carried out by Frank et al. (1976) determined the concentrations of 10 metals in agricultural soils in Ontario. Most of the soils had never received sewage biosolids, and a small number had received at least one application. A finding of that study was that high cadmium levels occurred in a few soils which had received past applications of sewage biosolids. A more recent study by Frank et al. (1979) also determined concentrations of five metals in agricultural soils which had received at least one application of sewage biosolids. A finding of that study was that the addition of sewage biosolids caused no significant elevations in the metal levels in the soils.

Some research studies have also been carried out in support of local land application programs. Research findings reported by Webber et al. (1987) determined metal concentrations of 13 metals in agricultural soils in the Regional Municipality of Halton. Metal concentrations were determined for soils which: 1) had received applications of sewage biosolids; and 2) had never received applications of sewage biosolids. Three findings of that study were: 1) the mean metal concentrations in the soils which had received sewage biosolids, and in the soils which had never received sewage biosolids, were similar and approximated or somewhat exceeded the means for uncontaminated soils in Ontario; 2) the mean metal concentrations were consistently less than the maximum permissible concentrations for soils receiving sewage biosolids and fell within the ranges of common values for Canadian soils; and 3) with the exception of very large sewage biosolids applications, the application of sewage biosolids had no consistent effect on the magnitudes and variabilities of metal concentrations in the soils. These and other findings of that study continue to be used extensively by the Region of Halton in its site selection process.

However, there have been no studies undertaken across Ontario at the farm field level to monitor pH, phosphorus and metal levels in soils which have received multiple applications of sewage biosolids. While research supports the limits established for those parameters in the current guidelines, the lack of monitoring efforts has resulted in limited field-level studies which provide supporting documentation of the guideline limits. The absence of such documentation has resulted in considerable scepticism and persistent health and safety concerns among the urban and rural communities of Ontario.

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Purpose and Objectives

The purpose of the field survey was to conduct a general benchmark study of pH, phosphorus and metal levels in selected agricultural soils which have received multiple applications of sewage biosolids, in order to provide documentation in support of the criteria for those parameters in the current guidelines.

The specific objectives of the field survey were:

- to determine pH, phosphorus and metal levels in agricultural soils which have received multiple applications of sewage biosolids;
- to compare the pH, phosphorus and metal levels in the treated soils to background levels in adjacent or nearby non-treated soils with similar physical characteristics;
- to determine the total amount (loading) of metals applied to the treated soils from applications of sewage biosolids;
- to determine the rate of build-up, if any, of metals in the soils which have received applications of sewage biosolids;
- to compare the findings to the permissible levels in the current guidelines; and
- to report the findings and make recommendations to OMAF senior management.

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Field Survey

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General

The 1995 OMAF field survey was undertaken in recognition of the ministry's responsibility to monitor critical parameters in soils which have received multiple applications of sewage biosolids for extended periods. It was also undertaken in response to public concerns related to health and safety as expressed by the urban and rural communities of the province.

A team of OMAF staff was assembled in the spring of 1995, and assigned the task of developing and carrying out the field survey. Site selection began in May and was completed in June. Field sampling began in July and was completed in September. Analysis of the soil samples was undertaken by the OMAF laboratories as they were received. Analysis of all samples was completed in October. Compilation of the report began in October and was completed in December.

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Parameters Included in the Survey

The field survey was a general study of three critical soil parameters which may be adversely affected by the application of sewage biosolids. The three parameters of concern were soil pH, soil phosphorus, and soil metal content. Each are discussed in more detail.

Soil pH

Soil pH is a measure of the acidity or alkalinity of the soil. This influences a number of

chemical, physical and biological properties of the soil. At soil pH of 6.0 or lower, most metals become more soluble and hence may be more available for plant uptake. Because sewage biosolids can be a source of metals, the current guidelines specify that sewage biosolids not be applied to acidic soils which have a pH of less than 6.0.

Soil acidity may be corrected by the addition of ground calcitic limestone (calcium carbonate) or ground dolomitic limestone (calcium and magnesium carbonate) to raise the pH. Because lime raises pH, sewage biosolids containing lime in quantities sufficient to raise the soil pH level above 6.0 may be applied to agricultural soils. Stabilizing sewage biosolids in this way is also effective in immobilizing many of the metals in the material.

Soil Phosphorus

Phosphorus is an essential nutrient for both plant and animal growth. As a plant nutrient, it promotes rapid vigorous growth and seedling development. In the soil, phosphorus is a relatively immobile nutrient that becomes attached to soil particles. Phosphorus may build up in the soil in varying forms of availability, due to the different phosphorous compounds and mineral complexes in the soil.

Phosphorus occurs in both inorganic (mineral) and organic forms in the soil. When phosphorus is released from soil minerals or organic matter, it may combine readily with: clay particles or calcium, iron, and aluminum ions in solution to form sparingly soluble precipitates. Excess phosphorus levels may result in fixation of iron and zinc, making those essential micro-nutrients less available to plants. It may also result in non-point source pollution of rivers and lakes, if run-off containing phosphorus rich material enters surface watercourses. Phosphorus which enters rivers and lakes promotes unwanted aquatic plant growth.

The chemical extractant recommended by OMAF to measure plant available phosphorus is the Olsen sodium bicarbonate method (OMAF, 1995). Sewage biosolids may not be applied to soils that contain more than 60 ppm of sodium bicarbonate extractable phosphorus in the top 15 cm of soil. While other chemical extractants may be used by industry to measure phosphorus, the resultant values cannot be converted into sodium bicarbonate values with any degree of reliability.

Soil Metal Content

The eleven elements of concern to agriculture are: arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), mercury (Hg), molybdenum (Mo), nickel (Ni), lead (Pb), selenium (Se), and zinc (Zn). All of these elements can be toxic to plants and animals, if they occur at high concentrations in agricultural soils. The concentrations at which toxicity commences vary from soil to soil and have not been firmly established.

Many published reports and scientific papers refer to all of these elements as metals. The current *Guidelines for Sewage Sludge Utilization on Agricultural Lands* (MOEE/OMAF, 1992) also refer to these elements as metals. However, arsenic and selenium are non-metal elements. While the authors recognize this discrepancy, the 11 elements referred to as metals in this report includes arsenic and selenium.

Metals such as cobalt, copper, selenium and zinc should be widely distributed and not concentrated on a few fields or farms. When metals have entered the soil they leach very little. As a result, metals may potentially accumulate in the soil and subsequently be taken up agricultural plants. Reduced plant growth or phytotoxicity (expressed as crop injury) are visible indicators of excess metal levels in agricultural soils. Severe phytotoxicity may kill some agricultural plants.

Arsenic and nickel have known toxic effects on plants. The maximum permissible levels for these metals in soils which have received sewage biosolids was set at twice the mean level in uncontaminated Ontario soils, as reported in the current guidelines.

Cadmium is a non-essential element for plant growth. It is considered to be the metal of greatest concern with respect to land application of sewage biosolids, because humans and animals have a low cadmium tolerance. Cadmium may be taken up and accumulate in the leafy tissue of plants. Subsequent ingestion of those plants by humans or livestock may then result in cadmium accumulation in the liver and kidneys, which can result in kidney damage. The maximum permissible level for cadmium was set at twice the mean level in uncontaminated Ontario soils.

Cobalt, copper and zinc are essential elements for plant growth, but are toxic to plants at high concentrations. Because some Ontario feed crops are deficient in these metals, the maximum permissible levels were set at four times the mean levels in uncontaminated Ontario soils, to allow for some soil build-up.

Chromium, mercury and lead are not required by plants, and are toxic to animals and humans at high concentrations. Plants take up these metals less readily than other metals. Therefore, the current guidelines permit higher concentrations of these metals in soils which have received sewage biosolids, compared to the permitted concentrations of the other metals. Although chromium is not required by plants, it has been found to be essential for animals and it may be deficient in human food. The maximum permissible levels for chromium, mercury and lead were set at 8, 5 and 4 times (respectively) the mean levels in uncontaminated Ontario soils.

Molybdenum is an essential element in human and animal diets, but is required only in trace amounts. Molybdenum may be leached from well-drained soils. Generally, it is not considered to be very toxic to humans. It can, however, accumulate in plants without causing plant injury. This fact, along with the susceptibility of ruminants to molybdenum toxicity, results in a concern in areas where sewage biosolids are utilized on land used to grow forage crops. The maximum permissible level was set at twice the mean level in uncontaminated Ontario soils.

Selenium has a narrow acceptable range in animal feeds. Because some Ontario feed crops are deficient in this metal, the maximum permissible level was set at four times the mean level in uncontaminated Ontario soils, to allow for some soil build-up.

Sewage biosolids should not be applied to agricultural soils which contain concentrations of one or more of the 11 metals above those specified in the current guidelines. The maximum permissible metal levels are given in Column 3 of Table 1.

The guidelines also limit the application of sewage biosolids on agricultural land if concentrations of one or more of the 11 metals in the sewage biosolids are greater than permissible levels. For anaerobically digested sewage biosolids, the permissible levels are based on nitrogen to metal ratios. For aerobically digested sewage biosolids, the levels are based on metal concentrations. The permissible levels for each material type are shown in Columns 2 and 4, respectively, in Table 2.

Using the information in Tables 1 and 2, projections have been made as to how long it would take to raise the soil metal concentrations to the maximum permissible levels. Molybdenum would reach its maximum permissible level in approximately 25 years (Column 5, Table 1). For the other 10 metals, the projected time ranges from 30 to 55 years, depending on the metal. These projections have been calculated using the mean metal content in uncontaminated Ontario soils (Column 2, Table 1), and the permissible metal concentrations for anaerobic or aerobic sewage biosolids (Columns 2 and 4, Table 2). The minimum number of years for a soil to reach its maximum permissible level may be higher or lower than those indicated in Table 1, if: 1) the natural metal concentrations in the soil are higher or lower than the mean determined for uncontaminated Ontario soils; or 2) the concentrations of metals in the sewage biosolids are lower than the permissible levels.

Table 1. Criteria for Metal Content in Soils

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Survey Methods

Site Selection

Agricultural fields which had received long-term, multiple applications of sewage biosolids were targeted in the survey as good candidates to study pH, phosphorus and metal levels.

The following criteria were used to select agricultural fields:

- the field had received sewage biosolids under the conditions specified in three separate MOEE approvals;
- the field was being used for agriculture;
- the field was adjacent to or near a field composed of similar soils, which had never received applications of sewage biosolids (see paragraph below);
- the field could be sampled easily in at least three areas;
- records of analysis of pH, phosphorus and metal levels were available for the sewage biosolids applied to the field under each MOEE approval;
- records of the volumes of sewage biosolids applied to the field were available;
- records of agricultural management practices, particularly cropping history, could be obtained for the field; and
- permission could be obtained to take soil samples.

Table 2. Criteria for Metals in Sewage Biosolids

In order to meet the survey objectives, background levels for pH, phosphorus and metal levels in the soils under non-treated conditions were required for comparison purposes in the study. Since sewage biosolids would have first been applied to most candidate sites prior to full implementation of the first guidelines in 1982, it was expected that pre-application records of analyses of pH, phosphorus and metal levels in the soils would not be available. The reason being, such analyses were not required by the MOEE in the site approval process prior to 1982. Consequently, adjacent or nearby fields composed of similar soils, but which had never received sewage biosolids were also targeted in order to determine background levels of pH, phosphorus and metals. Paired sites (treated + adjacent or nearby non-treated) were therefore selected in the survey.

The location of candidate sites was restricted to Southern Ontario. Requests to provide candidate sites in that area were then directed to: 1) MOEE Regional Biosolids Coordinators; and 2) Ontario Clean Water Agency (OCWA) Area Biosolids Coordinators. It was expected that those individuals would be able to provide the required number of candidate sites and historical site records. Although the MOEE and OCWA coordinators assisted in identifying sites, they were not able to provide complete historical records for most sites. Requests to provide the necessary records were then directed to the operators of the water treatment control plants which had generated the sewage biosolids, or individuals involved in the local sewage biosolids application programs in those areas.

Based on the site information obtained from all agencies, only 27 paired sites were considered to fulfil all of the site criteria previously listed. An additional 9 paired sites were selected for which there were good historical records, but the treated fields had only received sewage biosolids under two separate MOEE approvals rather than three. A total of 36 paired sites, consisting of 72 fields, were selected and sampled in the survey.

The survey team received excellent cooperation from farmers in the site selection process. Most farmers who were approached for permission readily agreed to cooperate in the survey. They provided valuable information in regards to site history, and in many cases were able to assist the survey team in identifying the best locations to sample. Some non-treated fields included in the survey were managed by neighbouring farmers. They also willingly participated in the survey. A total of 41 farmers cooperated in the survey.

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Soil Sampling and Data Collection

Soil variability and ease of sampling were important considerations in the survey. The fields selected were expected to encompass more than one soil landscape, and more than one soil type. Soil sampling began in July, so it was expected that fields planted to soybeans, grain or corn would be difficult to sample later in the survey when the crops matured. Therefore, in order to minimize soil variability and maximize ease of sampling, smaller areas or plots within each field were identified and sampled. Where possible, each area or sampled plot was located on the same soil landscape within each field. The average size of the sampled plots was approximately 4 ha.

Some nearby woodlots were also sampled in the survey to provide an indication of the natural (non-treated) levels in similar soils which have never been used for agricultural crop production. While not an integral component of the survey, it was hoped that some conclusions related to the three parameters could be arrived at after a comparison of the woodlot soil levels to the treated and non-treated soil levels. Twelve woodlots were sampled.

Soil samples were taken from the surface cultivated layer along three transects in each of the "treated", "non-treated", and "woodlot" plots. Each was a sub-sample of a composite of approximately 20 or more surface samples taken by soil probe (2 cm diameter), or approximately 8 or more samples taken by soil auger (7.5 cm diameter), at intervals greater than 10 m apart. The sampling interval varied depending on the length of the transect. A composite sample was collected along each of three transects. The materials were thoroughly mixed, and two sub-samples were then taken from each composite. One sample was then analyzed for soil pH and available phosphorus levels, and the other analyzed for metal levels.

It was assumed that, over time, the sewage biosolids had been incorporated into the surface layer to a depth of at least 20 cm by conventional tillage practices. It was also expected that sewage biosolids would have been applied to some candidate sites by injection to a depth of at least 20 cm. Surface samples were therefore taken from the organic rich cultivated layer (Ap horizon) to an average depth of 20 cm, or to the bottom of the cultivated layer if it occurred less than 20 cm from the surface.

A total of 520 soil samples were taken at all sites, with 16 of those samples being additional samples taken at the request of farmer cooperators to check levels in certain areas (i.e. depressions). The results of those analyses are not included in the study, but will be given to the farmer cooperators. In total, 504 samples were taken as part of the survey. Of those samples, 252 were analyzed for pH and phosphorus levels, and 252 were analyzed for metal concentrations.

The number of sites and total number of samples collected by region/county and sewage treatment plant (source of sewage biosolids), are given in Table 3.

The following information was also collected, during sampling, for each of the 36 paired sites included in the survey:

- Location - region/county, township, lot and concession;
- Site map - farm layout; location of treated and non-treated fields; location of woodlots; location of sampled plots; location and direction of transects; roads; other locational markers (e.g. trees, fencerows);
- Soil type - from the appropriate soil map;
- Soil texture - approximated from surface samples;
- Site history - 1995 crop; predominant crop or crop rotation; whether manure had been applied; any relevant site information; and
- Landowner or tenant - name, address, telephone number.

Table 3. Number of Sites and Samples by Region/County and Sewage Treatment Plant

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Soil Analysis

All samples for pH and phosphorus analysis were oven dried at 35°C for a period of 24 hours. All samples for metal analysis were air dried for a period of at least 24 hours. The soil materials were then sieved through screens 2 mm in size to attain uniform consistency and remove any foreign matter from the sample. Part of the prepared sample material was then used for analysis purposes.

Soil pH was determined by injecting the electrodes of a pH meter into saturated paste, and recording the readings. Available phosphorus (ppm) was determined using the Olsen sodium bicarbonate extraction method (OMAF, 1995). Both analyses were carried out by OMAF staff in the Nutrient Testing Laboratory at the Ridgetown College of Agricultural Technology, Ridgetown, according to ministry nutrient soil test procedures.

Metal concentrations (mg/g) were determined following hot acid leach using concentrated nitric acid, and all measurements were by ICP-AE spectroscopy and atomic absorption. The analysis was carried out by OMAF staff in the Pesticides and Trace Contaminants Laboratory, Guelph, according to ministry metal extraction soil test procedures.

Soil samples collected during the survey were analyzed to determine concentrations of the 11 elements specified in the current guidelines, namely: arsenic, cadmium, cobalt, chromium, copper, mercury, molybdenum, nickel, lead, selenium, and zinc.

Data Analysis/Interpretation

Site information and analytical results were input into Lotus 1,2,3 spreadsheet files programmed to determine average pH, phosphorus and metal levels for the soils in each individual sampled plot (36 treated, 36 non-treated, and 12 woodlot plots). The averages calculated for the individual sites were then imported into a SAS (Statistical Analysis System) computer program based on the Duncan Multiple Range Test. The SAS program was used to generate mean pH, phosphorus, and metal levels, and to determine the mean values which were significantly different at the 0.05 probability level.

The average pH, phosphorus and metal levels determined for the soils in the treated, non-treated, and woodlot sampled plots for each paired site were then compared to determine differences (+/-) in the levels of all parameters. Those differences, and the mean values determined for the treated, non-treated, and woodlot soils plots were then compared to the criteria in the current guidelines. Comparison of the average and mean values determined for the treated and non-treated soils was given the most emphasis.

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Site Descriptions and Locations

Abbreviated descriptions for the 36 paired sites are given in Table 4. Each description includes the general location of the site, and the following for the treated and non-treated plots which were sampled: the agricultural use (1995 Crop + Predominant Crop); whether the soils had received manure (yes or no - blank if not confirmed); the soil type; and the surface texture.

Soil type was not verified at each site. Rather, the soil type was identified from the appropriate soil map for the area. The surface texture at each site was approximated using hand texturing techniques to estimate sand, silt and clay content.

The locations of the paired sites are shown in Figure 1. Some paired sites occurred in very close proximity to other paired sites also included in the survey. Due to scale limitations, therefore, some locations shown in Figure 1 represent more than one paired site.

The survey team had hoped to locate sites in most areas of Southern Ontario where land application programs were in place. This was not possible because suitable soil and sewage biosolids records were not available for potential sites in some areas. A primary reason for the lack of suitable records was that site approvals have been issued to contracted haulers who maintained the records. Due to competitiveness in the industry, the contracted haulers change, and the site records are not passed on to the new haulers. As a result, the required records are not available.

Figure 1. Locations of the Sampled Sites

Table 4. Abbreviated Descriptions of the Sampled Sites - Treated and Non-treated Plots

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Analytical Results

- pH Levels
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- Metal Levels
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  - Cadmium
  - Cobalt
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- Table 5. Average pH, Phosphorus and Metal Levels by Site Number - Treated Plots
- Table 6. Average pH, Phosphorus and Metal Levels by Site Number - Non-treated Plots
- Table 7. Average pH, Phosphorus and Metal Levels by Site Number - Woodlot Plots
- Table 8. Mean, Maximum and Minimum Levels of all Parameters by Treatment
- Table 9. Summary of Transect Samples and Analysis by Individual Parameter

The pH, phosphorus and metal levels quoted in the following sections are given in Tables 5, 6, 7, 8, and 9. Soil analyses for pH and phosphorus levels were carried out on 252 transect samples, and analyses for 11 metal levels were also carried out on a similar number of samples taken along the same transects.

pH Levels

Twenty-two of the 252 transect samples tested had a pH level lower than the minimum permissible level of 6.0 as specified in the current guidelines. Eight of those transect samples were taken in the treated plots, 3 were taken in the non-treated plots, and 11 were taken in the woodlots. Minimum pH level in the treated, non-treated, and woodlot transect samples was 5.1, 5.4 and 5.3, respectively.

The mean pH levels over all 36 sites for the treated, non-treated, and woodlot soils were 7.1, 7.2 and 6.4, respectively. The mean pH level for the treated soils was not significantly different from the mean pH value for the non-treated soils. Three of the treated plots had an average soil pH value lower than 6.0. When compared to the non-treated plots for those sites, one of the non-treated plots (BL08) also had an average pH value lower than 6.0.

At 25 of the 36 paired sites, the average pH value of the treated plot was lower than the average pH value in the non-treated plot. However, only two of those sites had a difference in pH which was greater than 0.5.

For the sites where woodlot soils were also sampled, the mean pH values for the treated, non-treated and woodlot soils were 6.8, 6.9, and 6.4, respectively. None of the mean values were significantly different.

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Phosphorus Levels

Twelve of the 252 transect samples taken in all plots had available phosphorus levels higher than the maximum of 60 ppm as specified in the current guidelines. The maximum level in all transect samples taken in the treated plots was 111 ppm, and 7 of the 108 transect samples had phosphorus levels greater than 60 ppm. For the non-treated transects samples, the highest phosphorus level was 318 ppm and 5 transect samples had phosphorus levels greater than 60 ppm. The highest measured level in the woodlot transect samples was 24 ppm.

The mean phosphorus levels over all 36 sites for the treated, non-treated, and woodlot soils were 29.4, 17.3 and 9.3 ppm, respectively. The mean phosphorus level of the treated soils was not significantly different from the mean level for the non-treated soils. However, further study of the site record data determined that the non-treated soils at sites BL05, BL07, BL08 and LS02 were permanent pasture fields which also had received applications of manure. Elevated phosphorus levels due to the applications of manure would be expected, and were confirmed by the abnormally high average levels in the non-treated soils at those sites.

Those sites were therefore excluded from the data base, and statistical analysis was re-run on the analytical results for the remaining 32 sites. The resulting mean phosphorus levels for the treated and non-treated soils were 29.2 and 9.4 ppm, respectively. The mean phosphorus level for the treated soils was then significantly different from the mean level in the non-treated soils. At 29 of the 36 sites, the treated soil had a higher average available phosphorus level than the non-treated soil.

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Metal Levels

Arsenic

The arsenic level in all of the 252 transect samples was lower than the maximum permissible level of 14 ppm for treated (sludged) soils as specified in the current guidelines. For the treated, non-treated, and woodlot transect samples, the maximum levels measured were 7, 7, and 9 ppm, respectively. There were no samples testing lower than the method detection limit (MDL) of 0.5 ppm. At 10 of the 36 sites, the average arsenic level was higher in the treated soils than in the non-treated soils. The mean arsenic levels for the treated, non-treated and woodlot soils were 2.21, 2.24, and 2.06 ppm, respectively. The means for the treated and non-treated soils were not significantly different.

Cadmium

There were no transect samples with cadmium levels higher than the maximum permissible level of 1.6 ppm as specified in the current guidelines. Maximum levels measured in the treated, non-treated, and woodlot transect samples were 0.9, 0.9 and 1.0 ppm, respectively. A total of 210 of the 252 transect samples had cadmium levels which were lower than the MDL of 0.5 ppm. These were identified as Not Detected (ND) on the laboratory analysis records. Eighty-nine of those samples were taken in the treated plots, 92 were taken in the non-treated plots, and 29 were taken in the woodlots. Cadmium was only detected in 8 treated plots, 5 non-treated plots, and 4 woodlots. After the ND levels were replaced with the MDL of 0.5 ppm, the mean cadmium levels for the treated, non-treated and woodlot soils were 0.54, 0.52, and 0.52 ppm, respectively. The mean cadmium level for the treated soils was not significantly different from the mean level for the non-treated soils. However, interpretation of these means is limited because of the high number of MDL values used rather than actual measured levels.

Cobalt

The maximum cobalt levels found in the treated, non-treated, and woodlot transect samples were 10, 13 and 13 ppm, respectively. There were no samples over the maximum permissible level of 20 ppm as specified in the guidelines. The MDL was 2.5 ppm, and there

were 8, 9 and 5 samples below that limit in the treated, non-treated, and woodlot transect samples, respectively. After the ND levels were replaced with the MDL of 2.5 ppm, the mean cobalt levels for the treated, non-treated, and woodlot soils were 6.96, 6.95 and 6.46 ppm, respectively. The mean levels for the treated and non-treated soils were not significantly different.

Chromium

The maximum levels of chromium in the transect samples was 90 ppm in the treated samples, 24 ppm in the non-treated samples, and 15 ppm in the woodlot samples. The maximum permissible level is 120 ppm. Chromium levels in 44 transect samples were below the MDL of 10 ppm, with 10 of those samples being taken in the treated plots, 27 being taken in the non-treated plots, and 7 being taken in the woodlots. After the ND levels were replaced with the MDL of 10 ppm, the mean chromium levels for the treated, non-treated and woodlot soils were 18.5, 13.9, and 14.1 ppm, respectively. The mean chromium level in the treated soils was significantly different from the mean level in the non-treated soils. At 24 of the 36 sites, the average chromium level was higher in the treated soil than in the non-treated soil.

Copper

The maximum levels of copper measured in the transect samples were 37 ppm in the samples taken in the treated plots, 38 ppm in the samples taken in the non-treated plots, and 65 ppm in the samples taken in the woodlots. The maximum permissible level as per the guidelines is 100 ppm. Copper levels were below the MDL of 10 ppm in 47 of the transect samples (11 treated samples, 21 non-treated samples, and 15 woodlot samples). After the ND levels were replaced with the MDL of 10 ppm, the mean copper levels for the treated, non-treated, and woodlot soils were 21.6, 17.7, and 17.6 ppm, respectively. The mean copper level for the treated soils was significantly different from the mean level for the non-treated soils.

At 26 of the 36 sites, the average copper level in the treated soil was higher than the average level in the non-treated soil.

Mercury

The maximum levels of mercury in the transect samples were 0.2 ppm in the treated samples, 0.06 ppm in the non-treated samples, and 0.09 ppm in the woodlot samples. The levels in all samples were below the maximum permissible level of 0.5 ppm. Mercury was detected in all samples, and the MDL was 0.01 ppm. The mean mercury levels for the treated, non-treated and woodlot soils were 0.08, 0.05, and 0.08 ppm, respectively. The mean mercury level in the treated soils was significantly different from the mean level in the non-treated soils. At 28 of the 36 sites, the average mercury level in the treated soil was higher than in the average level in the non-treated soil.

Molybdenum

Molybdenum was not detected in any of the transect samples at the MDL of 2.5 ppm. The actual levels of molybdenum in the treated, non-treated, and woodlot soils were not determined, but would be less than 2.5 ppm.

Nickel

The maximum permissible level for nickel as per the guidelines is 32 ppm. At site BL01, one transect sample taken in the treated plot had a nickel level of 85 ppm, which was the maximum level in all samples taken in the treated plots. The other two transect samples taken in that plot had nickel levels of 12 ppm. The maximum nickel levels in the transect samples taken in the non-treated and woodlots plots were 31 and 16 ppm, respectively. Of the 252 transect samples, 107 samples had nickel levels below the MDL of 10 ppm (39 in

the treated plots, 51 in the non-treated plots, and 17 in the woodlots). After the ND levels were replaced with the MDL of 10 ppm, the mean nickel levels for the treated, non-treated and woodlot soils were 13.1, 12.6, and 12.1 ppm, respectively. The mean levels for the treated and non-treated soils were not significantly different.

Lead

The maximum levels of lead in the transect samples were 45 ppm in the samples taken in the treated plots, 39 ppm in the samples taken in the non-treated plots, and 28 ppm in the samples taken in the woodlots. None of the samples had levels greater than the maximum permissible level of 60 ppm. Lead was not detected in 26 treated samples, 38 non-treated samples, and 6 woodlot samples at the MDL of 10 ppm. After the ND levels were replaced with the MDL of 10 ppm, the mean lead levels for the treated, non-treated and woodlots soils were 14.3, 13.9, and 14.8 ppm, respectively. The mean levels for the treated and non-treated soils were not significantly different.

Selenium

The maximum permissible level of selenium is 1.6 ppm. At site BL06, transect samples taken in the treated plot and in the non-treated plot had selenium levels of 2.0 and 1.7 ppm, respectively. At site BL02, all 3 woodlot transect samples had levels above the maximum permissible level (1.8, 2.0, and 2.0 ppm). There were no transect samples which had levels below the MDL of 0.25 ppm. The mean selenium levels for the treated, non-treated, and woodlot soils were 0.89, 0.85, and 1.09 ppm, respectively. The mean levels for the treated and non-treated soils were not significantly different.

Zinc

The maximum permissible level of zinc is 220 ppm. At site BL05, one transect sample taken in the treated plot had a zinc level of 227 ppm. At site BL09, two of the transect samples taken in the non-treated plot had levels of 246 and 223 ppm, respectively. The maximum level in the woodlot samples was 130 ppm. The mean zinc levels in the treated, non-treated and woodlot soils were 57.1, 57.5, and 56.0 ppm, respectively. There were 7 transect samples with levels lower than the MDL of 25 ppm (1 treated, 6 non-treated).

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Table 5. Average pH, Phosphorus and Metal Levels by Site Number - Treated Plots

Table 6. Average pH, Phosphorus and Metal Levels by Site Number - Non-Treated Plots

Table 7. Average pH, Phosphorus and Metal Levels by Site Number - Woodlot Plots

Table 8. Mean, Maximum, and Minimum Levels for All Parameters by Treatment

Table 9. Summary of Number of Transect Samples and Analysis by Individual Parameter

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Analytical Results, Findings, and Recommendations of the 1995 OMAF Sewage Biosolids Field Survey

Interpretation of Analytical Results

- pH Levels
- Phosphorus Levels
- Metal Levels
- Comparison to the Current Guidelines

pH Levels

The mean pH of the treated soils (7.1) was marginally lower than the mean pH for the non-treated soils (7.2). However, based on statistical analysis of the analytical results, the addition of sewage biosolids to the soils in the treated plots has had no significant effect on soil pH. This finding is consistent with other reported findings when sewage biosolids were applied to agricultural soils (Gestring, 1982; Soon, 1978).

For only those sites where woodlot soils were also sampled, the mean pH levels for the treated, non-treated and woodlots soils were 6.8, 6.9, and 6.4, respectively. None of the means were significantly different. These findings indicate that, for those sites, agricultural use has not had a significant effect on soil pH.

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Phosphorus Levels

The mean phosphorus level for the treated soils at 32 sites (29.2 ppm) was significantly different from the mean level for the non-treated soils (9.4 ppm). This finding indicates that the addition of sewage biosolids to the treated soils has had a significant positive effect on the amount of available phosphorus. The mean level of 29.2 ppm of phosphorus in the treated soils is not excessive. Phosphorus levels of 50-60 ppm are necessary in order to successfully grow some agricultural crops (OMAFRA, 1995). It would appear from these findings that municipal sewage biosolids are an excellent source of phosphorus. It would also appear that, through controlled application rates and crop utilization, available soil phosphorus is being maintained at acceptable levels. At 29 of the 36 sites, the average available phosphorus level of the treated soil was higher than the average level for the non-treated soil.

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Metal Levels

The mean arsenic and zinc levels for the treated soils were lower than the mean levels for the non-treated soils. Excluding molybdenum, the mean levels for the other 8 metals were all higher in the treated soils than in the non-treated soils. The mean levels for all metals were all well below the maximum permissible levels. Mean levels for molybdenum for both the treated and non-treated soils were not determined because the concentrations in all soil samples were below the method detection limit of 2.5 ppm. The mean levels for both treatments would be less than 2.5 ppm. The maximum permissible level for molybdenum is 4 ppm.

Chromium, copper and mercury levels in the treated soils were significantly elevated, but the resulting

levels were well below the maximum permissible levels. Excluding molybdenum, the mean levels of the other 7 metals for the treated soils were not significantly different from the mean levels for the non-treated soils. These findings indicate that the application of sewage biosolids to the treated soils has had a significant positive effect on chromium, copper and mercury levels. It has had no significant effect on the levels of the other 7 metals.

The mean cobalt, selenium and zinc levels for the non-treated soils were higher than the mean levels for those metals in uncontaminated Ontario soils, as given in Column 2 of Table 1, and listed in the current guidelines. However, the mean levels were equal to or lower than the mean levels for "Rural Parkland" soils as reported in the *Ontario Typical Range of Chemical Parameters in Soil, Vegetation, Moss Bags and Snow* (MOEE, 1993).

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Comparison to the Current Guidelines

Three of the 108 transect samples taken in the treated plots had 1 metal level which was higher than the maximum permissible level shown in Table 1, and also reported in the current guidelines. Treated site BL01 was the only site with an average metal level (nickel, 36.33 ppm) which was higher than the permissible level (32 ppm). However, the individual transect sample levels for nickel were 85 ppm, 12 ppm, and 12 ppm. In light of the two low levels, the 85 ppm level was considered abnormally high and was likely due to contamination during sampling. The sample was not retested due to time constraints.

The soils in 31 of the 36 treated plots had at least 1 average metal level which was lower than the maximum permissible level, but was higher than the average level in the soils in the comparison non-treated plot. Thirty-eight of 396 average levels determined for all metals in the treated soils exceeded 50% of the maximum permissible level. Twenty-three of those levels were higher than the average levels in the comparison non-treated soils.

Excluding molybdenum, the mean levels for the other 10 metals in the treated soils were all well below the maximum permissable levels specified in the guidelines. Although the mean level for molybdenum could not be determined, it would be less than 2.5 ppm (the MDL), which is below the maximum permissible level of 4 ppm. The mean levels for all metals in the treated soils are given in Table 5.

Except for cobalt, molybdenum, selenium and zinc, the mean levels of the other 7 metals for the non-treated soils were lower than the mean levels for uncontaminated Ontario soils, as given in Column 2 of Table 1, and reported in the current guidelines.

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Analytical Results, Findings, and Recommendations of the 1995 OMAF Sewage Biosolids Field Survey

Conclusions

The findings described in the preceding sections indicate that:

- multiple applications of sewage biosolids have had no significant effect on soil pH;
- agricultural use at the sites where woodlot soils were also sampled has had no significant effect on soil pH;
- excess phosphorus levels are not a concern in soils which have received multiple applications of sewage biosolids;
- multiple applications of sewage biosolids have had a significant positive effect on available phosphorus levels in the soils;
- municipal sewage biosolids appear to be an excellent source of phosphorus;
- through controlled application rates and crop production, available soil phosphorus is being maintained at acceptable levels in soils which have received multiple applications of sewage biosolids;
- excess metal levels are not a concern in soils which have received multiple applications of sewage biosolids, and all mean metal levels for those soils were below the maximum permissible levels;
- multiple applications of sewage biosolids have had a significant positive effect on chromium, copper and mercury levels in the soils, but the resulting levels were well below the maximum permissible levels;
- based on the mean metal levels determined for the non-treated soils, the number of years it would take for all metals except cobalt, molybdenum, selenium and zinc, to reach the maximum permissible content would be greater than the number of years reported in the current guidelines.

With respect to the study objectives to also determine metal loading and rates of build-up, there was insufficient data available for most of the sites to establish loading or possible rates of build-up for metals. Complete records of pre-application soil analyses, and sewage biosolids quality and application rates, were not available for many sites.

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Analytical Results, Findings, and Recommendations of the 1995 OMAF Sewage Biosolids Field Survey

Recommendations

1. **Monitoring of critical soil parameters which may be adversely affected by the application of sewage biosolids should be an on-going process.**

   Soils treated with sewage biosolids should be routinely analyzed for pH, phosphorus, and the 11 metals of concern specified in the current guidelines. This will ensure that: 1) the levels of those parameters in the soils are acceptable according to the current guidelines; and 2) complete records are kept which are suitable for future monitoring.

   Monitoring of other critical soil parameters of public concern (i.e. industrial organic compounds) could be undertaken in future surveys of this type.

2. **Nutrient management plans should be established for all approved sewage biosolids utilization sites.**

   Nutrient management plans established in co-operation with the landowner would allow for better utilization of the nutrients in the sewage biosolids applied to agricultural lands. Such plans would give the landowner a more accurate picture of nutrient availability and requirements when establishing a cropping program. They should be established as part of the site approval process.

3. **A more consistent and complete record keeping system needs to be established to facilitate future monitoring and verification of utilization sites.**

   Records are the key to any monitoring process. In order to monitor the sewage biosolids land application program properly, it is necessary to have complete and accessible records. The inaccessibility and incompleteness of the existing biosolids application records for the sites included in the field survey was a major deficiency.
   Sewage biosolids application records should include: analyses of soil samples taken on a regular basis (pH, phosphorus and metals); accurate site maps showing individual fields, and updated as necessary (i.e. when revisions are made to the Certificate of Approval); accurate application quantity and quality information, by field; and a nutrient management plan.

   It is recommended that these records be kept by the generator of the sewage biosolids (i.e. at the sewage treatment plant). A copy should also be given to the landowner.

4. There should be some further study of the analytical results included in this report, and of the loading and rates of build-up of phosphorus and metals in the soils included in the study.

   Although the necessary data is not available for all sites included in the field survey, there may be sufficient data for some sites to look further into the loading rates, rates of build-up and possible fate of phosphorus and metals applied to the soils. It is recommended that the survey team review the data and report on its status at a later date.

5. **There should be further study of the possibility of nutrient and metal stratification in soils receiving injected and non-incorporated sewage biosolids.**

   The potentially adverse impact of nutrient and metal stratification in soils where sewage biosolids are injected, or surface applied without incorporation, needs to be investigated.

6. **Analysis of soil organic matter and clay levels should also be undertaken in future monitoring or site verification studies.**

   Documented research has shown that metal concentrations are related to the organic matter and clay levels in the soil. It is recommended that analysis of these parameters also be undertaken in future studies of this type.

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Table 1. Criteria for Metal Content in Soils[1]

1	2	3	4	5
Metal	Mean Metal Content in Uncontaminated Ontario Soils (mg/g)	Maximum Permissible Metal Content in Sludged soils (mg/g)	Maximum Permissible Metal Addition to Uncontaminated Soil (kg/ha)	Minimum Number of years to reach Max. Permissible Metal Content in Soil based on the three previous columns
ARSENIC	7	14	14	50
CADMIUM	0.8	1.6	1.6	30
COBALT	5	20	30	55
CHROMIUM	15	120	210	45
COPPER	25	100	150	55
MERCURY	0.1	0.5	0.8	45
MOLYBDENUM	2	4	4	25
NICKEL	16	32	32	45
LEAD	15	60	90	50
SELENIUM	0.4	1.6	2.4	45
ZINC	55	220	330	50

[1] From *Guidelines for Sewage Sludge Utilization on Agricultural Lands* (MOEE/OMAF, 1992).

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Table 2. Criteria for Metals in Sewage Biosolids[1]

Metals	Anaerobic Sludges		Aerobic Sludges	
	Minimum Ammonium plus Nitrate Nitrogen to Metal Ratios		Maximum Permissible Metal Concentrations (mg/g solids)	
	Present Requirements	Long-term Targets	Present Requirements	Long-term Targets
ARSENIC	100	480	170	35
CADMIUM	500	4200	34	4
COBALT	50	220	340	77
CHROMIUM	6	32	2800	530
COPPER	10	45	1700	380
MERCURY	1500	8400	11	1.4
MOLYBDENUM	180	1700	94	1.2
NICKEL	40	210	420	80
LEAD	15	75	1100	220
SELENIUM	500	2800	34	6
ZINC	4	20	4200	840

[1] From *Guidelines for Sewage Sludge Utilization on Agricultural Lands* (MOEE/OMAFRA, 1992).

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Table 3. Number of Sites and Samples by Region/County and Sewage Treatment Plant

Region/County	Sewage Treatment Plant	# of Paired Sites	# of Soil Samples[1]					
			Treated		Non-treated		Woodlot	
			pH, P[2]	Met.[3]	pH, P	Met.	pH, P	Met.
Regional Municipality of Durham	All (blended)	7	21	21	21	21		
Regional Municipality of Halton	All (blended)	5	15	15	15	15		
Regional Municipality of Niagara	Grimsby Thorold	1 1	3 3	3 3	3 3	3 3		
Regional Municipality of Waterloo	Kitchener	4	12	12	12	12	3	3
Bruce County	Southampton Hanover	1 3	3 9	3 9	3 9	3 9		
Frontenac County	Kingston	4	12	12	12	12	9	9
Grey County	Owen Sound Hanover	1 2	3 6	3 6	3 6	3 6	3	3
Huron County	Blyth Brussels	1 1	3 3	3 3	3 3	3 3	3 3	3 3
Leeds County	Kingston	1	3	3	3	3	3	3
Lennox & Addington Counties	Kingston	1	3	3	3	3	3	3
Northumberland County	Cobourg	3	9	9	9	9	9	9
TOTALS		**36**	**108**	**108**	**108**	**108**	**36**	**36**

[1] Includes all samples taken as part of the survey.

[2] pH, P - number of samples taken for analysis of pH and phosphorus levels.

[3] Met. - number of samples taken for analysis of metal levels.

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Table 4. Abbreviated Descriptions of the Sampled Sites - Treated and Non-treated Plots

Site No.	Location	Sampled Plots									
		Treated					Non-treated				
		Agricultural Use			Soil Features		Agricultural Use			Soil Features	
		1995	Predom.	Manure?	Soil Type	Soil Tex.[1]	1995	Predom.	Manure?	Soil Type	Soil Tex.[1]
BL01	Huron	Corn	Corn, Beans		Harriston	L	Hay	Hay		Harriston	L
BL02	Huron	Hay	Hay		Listowel	SiL	Corn	Corn, Beans		Listowel	SiL
BL03	Waterloo	Corn	Corn, Beans	No	Brady	SL	Corn	Corn, Beans, Wheat	No	Brady	SL
BL04	Waterloo	Corn	Hay		Caledon	SL	Pasture	Pasture		Caledon	SL
BL05	Waterloo	Pasture	Pasture		Fox	SL	Pasture	Pasture	Yes	Fox	SL
BL06	Bruce	Hay	Hay		Fox	L	Hay	Hay		Fox	L
BL07	Bruce	Corn	Hay		Fox	L	Pasture	Pasture	Yes	Fox	L
BL08	Niagara	Corn	Corn, Beans		Peel	C	Corn	Corn, Beans		Peel	C
BL09	Niagara	Wheat	Hay		Chinguacousy	CL	Aband. Pasture	Aband. Pasture	Yes	Chinguacousy	CL
LS01	Bruce	Pasture	Pasture	Yes	Listowel	FSL	Pasture	Pasture	No	Listowel	FSL
LS02	Grey	Corn	Hay/corn	Yes	Harkaway	L	Pasture	Pasture	Yes	Harkaway	L
LS03	Waterloo	Sod	Sod	No	Guelph	L/SL	Sod	Sod	No	Guelph	L/SL
LS04	Grey	Alfalfa	Hay	Yes	Burford	GL	Clover	Hay	No	Burford	GL
LS05	Grey	Fallow	Hay	No	Sullivan	SL	Hay	Hay	No	Sullivan	SL
LS06	Bruce	Hay	Hay + grain		Burford	L	Pasture	Pasture	Yes	Burford	L

LS07	Durham	Corn	Corn, Beans	No	Dundonald	VFSL	Sod	Sod	No	Dundonald	VFSL
LS08	Durham	Fallow	Hay + grain	No	Darlington	L	Beans	Hay + grain	Yes	Darlington	L
LS09	Durham	Hay + corn	Corn	Yes	Bondhead	VFSL	Alfalfa	Corn	Yes	Bondhead	VFSL
LS10	Durham	Pasture	Pasture	No	Granby	SL	Pasture	Pasture	No	Granby	SL
MJ01	Halton	Vol. Wheat	Corn/ beans/ grain	No	Chinguacousy	L	Pasture	Pasture	No	Chinguacousy	L
MJ02	Halton	Beans	Beans/ Clover		Oneida	CL	Clover	Beans/ Clover		Chinguacousy	CL
MJ03	Halton	Corn	Corn + hay		Chinguacousy	CL	Beans	Hay + grain		Oneida	CL
MJ04	Halton	Grain	Grain + hay		Chinguacousy	CL	Grain	Grain + hay		Oneida	CL
MJ05	Halton	Beans	Beans/ corn		Chinguacousy	L-CL	Beans	Beans + corn		Gilford	L-CL
MJ06	Durham	Alfalfa	Hay + grain	Yes	Darlington	FSL	Alfalfa	Hay + grain	Yes	Darlington	L-CL
MJ07	Durham	Hay	Hay	Yes	Tecumseth	L-SL	Hay	Hay	Yes	Tecumseth	L-SL
MJ08	Durham	Wheat	Beans + grain	Yes	Darlington	GSL	Alfalfa	Corn + hay		Darlington	GSL
MP01	Leeds	Hay/ Pasture	Hay/ Pasture		North Gower	L-FSL	Pasture	Pasture		North Gower	L-FSL
MP02	Frontenac	Hay/ Pasture	Hay/ Pasture		Napanee	C	Hay/ Pasture	Hay/ Pasture		Napanee	C
MP03	Frontenac	Hay/ Pasture	Hay/ Pasture		Napanee	C	Hay/ Pasture	Hay/ Pasture		Napanee	C
MP04	Frontenac	Alfalfa	Hay + grain		Farmington	L	Alfalfa	Hay		Farmington	L
MP05	Frontenac	Alfalfa	Hay + grain		Bondhead	L	Grain	Hay + grain		Bondhead	L
MP06	Lennox & Addington	Hay	Hay		Farmington	SL	Hay	Hay		Farmington	SL
MP07	Northum-berland	Corn	Corn + Hay	Yes	Percy	SL	Grain	Corn + Hay	Yes	Percy	SL
MP08	Northum-	Hay	Corn +	No	Dundonald	VFSL	Corn	Corn +	No	Dundonald	VFSL

	berland		Hay					Hay			
MP09	Northum-berland	Pasture	Pasture		Bondhead	SL	Pasture	Pasture		Bondhead	SL

[1] Legend:

GSL	- Gravelly sandy loam
SL	- Sandy loam
FSL	- Fine sandy loam
VFSL	- Very fine sandy loam
GL	- Gravelly loam
L	- Loam
CL	- Clay loam
C	- Clay

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Table 5. Average pH, Phosphorus and Metal Levels by Site Number - Treated Plots

Parameter		Average Levels for Individual Parameters (Phos. - ppm)(Metals - mg/kg)												
		pH	Phos. (P2O5)	As	Cd	Co	Cr	Cu	Hg	Mo	Ni	Pb	Se	Zn
Max. Permissible Level in Sludged Soils		-	60	14	1.6	20	120	100	0.5	4	32	60	1.6	220
Site Identification														
BL01	Treated	7.43	26.00	1.67	0.60	6.67	39.33	23.00	0.067	2.5	36.33	11.67	1.00	44.33
BL02	Treated	7.08	18.67	2.00	0.50	10.00	11.00	12.67	0.060	2.5	10.67	12.00	1.37	45.67
BL03	Treated	6.70	20.33	2.00	0.50	4.67	10.00	14.00	0.037	2.5	10.00	10.00	1.07	47.67
BL04	Treated	7.57	47.00	1.00	0.50	8.00	18.67	22.00	0.050	2.5	10.67	10.33	0.87	76.33
BL05	Treated	6.53	41.20	1.33	0.60	10.33	55.00	58.67	0.160	2.5	23.33	30.00	1.03	184.67
BL06	Treated	7.60	28.67	3.33	0.50	11.67	11.00	29.33	0.090	2.5	10.67	10.00	1.33	48.33
BL07	Treated	7.30	27.67	2.00	0.53	8.67	10.33	25.00	0.083	2.5	10.00	10.00	1.20	42.33
BL08	Treated	5.47	29.00	3.33	0.50	6.67	10.33	18.67	0.067	2.5	10.67	14.67	0.97	45.67
BL09	Treated	6.98	26.33	2.00	0.50	10.67	16.33	23.00	0.080	2.5	16.00	23.67	0.47	96.00
LS01	Treated	7.57	6.67	2.67	0.50	3.00	10.00	18.67	0.080	2.5	10.00	13.33	0.60	27.33
LS02	Treated	7.13	27.00	6.67	0.50	5.67	12.33	34.67	0.063	2.5	10.00	19.00	0.53	39.00
LS03	Treated	7.53	17.67	3.67	0.50	3.00	14.00	18.00	0.070	2.5	10.00	19.67	0.83	61.00
LS04	Treated	7.60	29.33	6.00	0.77	4.67	12.33	32.67	0.110	2.5	10.33	20.67	0.90	43.33
LS05	Treated	7.60	41.33	1.33	0.77	5.67	10.00	26.67	0.057	2.5	10.33	12.00	0.93	38.33
LS06	Treated	7.60	36.67	1.00	0.83	7.00	10.00	27.67	0.073	2.5	10.00	10.33	1.10	43.00

Table 5. (continued)

Parameter		Average Levels for Individual Parameters (Phos. - ppm)(Metals - mg/kg)											
		pH	Phos. (P2O5)	As	Cd	Co	Cr	Cu	Hg	Mo	Ni	Pb	Se	Zn
Max. Permissible Level in Sludged Soils		-	60	14	1.6	20	120	100	0.5	4	32	60	1.6	220
Site Identification														
LS07	Treated	7.43	28.33	1.67	0.50	2.50	12.33	12.67	0.033	2.5	10.00	10.00	0.33	35.33
LS08	Treated	7.27	12.33	2.33	0.50	5.33	14.67	12.67	0.043	2.5	10.00	10.33	0.37	44.67
LS09	Treated	7.67	52.00	2.67	0.50	7.00	15.00	12.00	0.053	2.5	10.00	11.00	0.33	42.00
LS10	Treated	7.87	11.33	1.33	0.50	3.67	18.33	13.67	0.067	2.5	19.00	21.00	0.50	60.00
MJ01	Treated	6.33	25.67	1.33	0.50	9.33	17.33	25.33	0.080	2.5	16.33	25.00	0.50	78.67
MJ02	Treated	7.20	17.67	3.33	0.50	10.00	12.67	21.33	0.063	2.5	14.33	13.33	1.27	56.33
MJ03	Treated	7.17	28.00	3.33	0.73	8.33	14.67	28.00	0.090	2.5	14.67	16.33	1.37	75.67
MJ04	Treated	6.97	23.00	3.67	0.50	9.33	14.33	22.00	0.053	2.5	13.67	13.00	1.23	57.33
MJ05	Treated	6.47	42.67	3.00	0.50	7.67	15.00	23.33	0.057	2.5	14.33	15.33	1.00	60.33
MJ06	Treated	7.83	47.67	2.67	0.50	2.83	13.67	15.67	0.053	2.5	10.33	16.00	0.87	46.67
MJ07	Treated	7.58	5.00	2.00	0.50	3.83	14.33	10.00	0.047	2.5	10.33	10.33	0.87	47.00
MJ08	Treated	7.55	89.00	1.33	0.50	3.67	30.00	23.67	0.090	2.5	10.00	10.00	0.77	47.00
MP01	Treated	5.90	25.33	1.33	0.50	7.00	20.67	22.67	0.120	2.5	10.00	10.00	1.00	56.00
MP02	Treated	6.37	38.33	1.00	0.50	11.00	29.67	28.00	0.163	2.5	17.33	15.67	1.23	87.67
MP03	Treated	6.43	19.67	1.33	0.50	9.00	21.67	19.33	0.100	2.5	15.33	14.00	1.13	72.67

Table 5. (continued)

Parameter		Average Levels for Individual Parameters (Phos. - ppm)(Metals - mg/kg)											
		pH	Phos. (P2O5)	As	Cd	Co	Cr	Cu	Hg	Mo	Ni	Pb	Se	Zn
Max. Permissible Level in Sludged Soils		-	60	14	1.6	20	120	100	0.5	4	32	60	1.6	220
Site Identification														
MP04	Treated	5.77	25.67	1.00	0.50	16.00	26.33	24.33	0.087	2.5	19.33	12.33	1.27	89.67
MP05	Treated	6.90	28.00	1.00	0.50	10.00	22.67	18.00	0.093	2.5	13.33	10.67	1.17	47.00
MP06	Treated	6.73	48.67	2.00	0.50	10.33	25.33	29.67	0.223	2.5	11.67	13.67	0.80	63.33
MP07	Treated	7.70	26.00	1.33	0.50	5.67	29.00	10.00	0.050	2.5	11.33	13.33	0.37	43.00
MP08	Treated	6.82	35.00	1.00	0.50	3.00	37.00	10.00	0.037	2.5	10.00	11.67	0.67	32.00
MP09	Treated	6.87	6.67	1.00	0.53	2.83	10.00	10.00	0.053	2.5	10.00	10.00	1.00	30.67
Number of Sites		36	36	36	36	36	36	36	36	36	36	36	36	36
Mean Level		7.1	29.4	2.21	0.54	6.96	18.5	21.6	0.08	<2.5	13.1	14.3	0.89	57.1
Maximum Level		7.87	89.00	6.67	0.83	16.00	55.00	58.67	0.22	<2.5	36.33	30.00	1.37	184.67
Minimum Level		5.47	5.00	1.00	<0.5	<2.5	<10	<10	0.03	<2.5	<10	<10	0.33	27.33

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Table 6. Average pH, Phosphorus and Metal Levels by Site Number - Non-Treated Plots

Parameter		Average Levels for Individual Parameters (Phos. - ppm)(Metals - mg/kg)												
		pH	Phos. (P2O5)	As	Cd	Co	Cr	Cu	Hg	Mo	Ni	Pb	Se	Zn
Max. Permissible Level in Sludged Soils		-	60	14	1.6	20	120	100	0.5	4	32	60	1.6	220
Site Identification														
BL01	Non-Treated	6.93	1.50	1.67	0.50	7.67	14.00	18.67	0.067	2.5	12.33	15.67	1.07	51.33
BL02	Non-Treated	7.23	42.33	2.33	0.50	9.33	13.33	14.67	0.047	2.5	11.67	10.00	1.07	55.33
BL03	Non-Treated	7.08	22.00	1.67	0.50	6.00	10.67	11.00	0.053	2.5	10.00	10.00	0.87	58.00
BL04	Non-Treated	7.27	26.00	1.00	0.50	6.33	10.00	12.67	0.030	2.5	10.00	10.00	0.87	48.00
BL05	Non-Treated	6.67	204.67	1.00	0.50	8.33	16.00	34.33	0.067	2.5	11.33	20.00	0.80	145.67
BL06	Non-Treated	7.67	4.67	1.33	0.50	12.00	11.33	24.67	0.047	2.5	12.33	10.00	1.30	40.67
BL07	Non-Treated	7.30	30.00	2.00	0.63	7.33	10.33	18.33	0.087	2.5	10.00	10.00	1.03	40.00
BL08	Non-Treated	5.77	21.33	2.33	0.50	10.00	12.67	13.67	0.057	2.5	15.67	15.33	0.83	54.00
BL09	Non-Treated	7.50	6.00	2.00	0.50	7.67	13.33	22.00	0.057	2.5	13.67	32.67	0.40	225.00
LS01	Non-Treated	7.57	1.67	2.67	0.50	3.33	11.33	15.00	0.050	2.5	10.00	13.67	0.53	32.00
LS02	Non-Treated	7.00	66.67	7.00	0.50	6.67	11.00	28.67	0.043	2.5	11.00	15.67	0.50	43.00
LS03	Non-Treated	7.57	15.33	5.00	0.50	3.67	11.00	28.00	0.047	2.5	10.00	28.67	0.50	61.00
LS04	Non-Treated	7.57	2.00	5.33	0.50	4.33	10.67	21.33	0.060	2.5	10.00	20.00	0.57	40.33
LS05	Non-Treated	7.73	2.67	1.33	0.80	5.00	10.00	26.00	0.047	2.5	10.33	10.00	1.03	38.00
LS06	Non-Treated	7.67	5.33	1.00	0.63	6.33	17.67	18.67	0.047	2.5	17.33	10.00	1.13	44.33

Table 6. (continued)

Parameter		Average Levels for Individual Parameters (Phos. - ppm)(Metals - mg/kg)												
		pH	Phos. (P205)	As	Cd	Co	Cr	Cu	Hg	Mo	Ni	Pb	Se	Zn
Max. Permissible Level in Sludged Soils		-	60	14	1.6	20	120	100	0.5	4	32	60	1.6	220
Site Identification														
LS07	Non-Treated	7.40	10.33	2.00	0.50	2.50	10.00	10.00	0.020	2.5	10.00	10.00	0.33	30.33
LS08	Non-Treated	7.93	12.00	1.33	0.50	5.67	15.33	11.67	0.043	2.5	10.00	10.33	0.30	44.00
LS09	Non-Treated	7.33	20.33	1.33	0.50	3.67	10.00	10.00	0.037	2.5	10.00	11.00	0.33	28.67
LS10	Non-Treated	7.80	10.00	1.33	0.50	3.67	13.67	14.00	0.073	2.5	11.00	20.00	0.50	51.67
MB01	Non-Treated	7.33	26.33	3.00	0.50	10.33	15.67	23.33	0.080	2.5	17.33	27.33	0.40	71.67
MB02	Non-Treated	7.80	5.00	3.33	0.50	9.67	15.33	25.33	0.077	2.5	15.33	17.00	1.47	68.67
MB03	Non-Treated	6.20	4.00	3.33	0.50	7.67	11.00	18.67	0.040	2.5	13.00	14.33	1.53	64.00
MB04	Non-Treated	7.30	15.00	2.67	0.50	8.33	12.00	15.00	0.030	2.5	15.33	11.67	1.20	48.67
MB05	Non-Treated	6.80	5.33	7.00	0.50	5.67	10.67	30.33	0.067	2.5	10.67	18.33	1.20	69.67
MB06	Non-Treated	7.93	13.33	1.33	0.50	4.00	13.67	13.67	0.050	2.5	10.67	13.00	1.00	47.00
MB07	Non-Treated	7.98	1.33	2.00	0.50	3.00	11.00	10.67	0.047	2.5	10.00	10.00	0.93	39.33
MB08	Non-Treated	7.77	3.67	3.00	0.50	3.67	10.67	10.00	0.037	2.5	10.00	10.00	0.77	47.00
MP01	Non-Treated	6.53	7.67	1.00	0.50	7.00	18.67	13.67	0.040	2.5	13.00	10.33	1.00	56.33
MP02	Non-Treated	6.63	4.33	1.00	0.50	13.00	29.33	26.00	0.057	2.5	24.33	12.00	1.17	92.67
MP03	Non-Treated	6.77	3.33	1.00	0.50	11.67	26.67	26.33	0.060	2.5	24.00	12.33	1.17	85.00

Table 6. (continued)

Parameter		Average Levels for Individual Parameters (Phos. - ppm)(Metals - mg/kg)												
		pH	Phos. (P205)	As	Cd	Co	Cr	Cu	Hg	Mo	Ni	Pb	Se	Zn
Max. Permissible Level in Sludged Soils		-	60	14	1.6	20	120	100	0.5	4	32	60	1.6	220
Site Identification														
MP04	Non-Treated	6.10	3.00	1.00	0.50	15.67	25.00	17.33	0.033	2.5	18.67	10.33	1.13	80.00
MP05	Non-Treated	6.67	8.00	1.33	0.50	11.00	17.00	11.00	0.037	2.5	13.00	10.00	1.07	43.67
MP06	Non-Treated	6.60	2.00	2.33	0.50	9.67	13.33	10.67	0.043	2.5	10.00	10.67	0.73	41.00
MP07	Non-Treated	7.87	4.67	1.33	0.50	5.33	20.33	10.33	0.030	2.5	10.00	10.00	0.33	33.67
MP08	Non-Treated	7.73	2.00	1.00	0.50	2.50	10.00	10.00	0.023	2.5	10.00	10.00	0.60	25.00
MP09	Non-Treated	7.07	6.67	1.33	0.50	2.50	10.00	10.00	0.030	2.5	10.00	10.00	0.83	25.00
Number of Sites		36	35	36	36	36	36	36	36	36	36	36	36	36
Mean Level		7.2	17.3	2.24	0.52	6.95	13.9	17.7	0.05	<2.5	12.6	13.9	0.85	57.5
Maximum Level		7.98	204.67	7.00	0.80	15.67	29.33	34.33	0.09	<2.5	24.33	32.67	1.53	225.00
Minimum Level		5.77	1.33	1.00	<0.5	<2.5	<10	<10	0.02	<2.5	<10	<10	0.30	<25

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Table 7. Average pH, Phosphorus and Metal Levels by Site Number - Woodlot Plots

Parameter		Average Levels for Individual Parameters (Phos. - ppm)(Metals - mg/kg)												
		pH	Phos. (P2O5)	As	Cd	Co	Cr	Cu	Hg	Mo	Ni	Pb	Se	Zn
Max. Permissable Level in Sludged Soils		-	60	14	1.6	20	120	100	0.5	4	32	60	1.6	220
Site Identification														
BL01	Woodlot	6.87	2.50	1.00	0.50	7.67	16.00	30.33	0.120	2.5	11.00	20.33	1.50	54.00
BL02	Woodlot	7.17	1.83	1.00	0.77	5.33	20.00	54.67	0.197	2.5	19.33	14.00	1.93	108.00
BL03	Woodlot	7.40	21.00	1.00	0.50	6.00	10.00	13.00	0.060	2.5	10.00	13.33	1.13	39.33
LS02	Woodlot	7.17	4.00	8.00	0.50	6.33	11.67	26.33	0.093	2.5	11.67	23.67	0.67	49.33
MP01	Woodlot	5.37	7.00	1.00	0.50	3.67	10.00	10.00	0.063	2.5	10.00	13.00	1.13	36.00
MP03	Woodlot	5.83	6.33	2.00	0.50	9.67	16.33	13.00	0.067	2.5	13.00	19.33	1.27	72.33
MP04	Woodlot	5.57	6.00	1.00	0.50	9.67	17.00	11.00	0.053	2.5	12.00	13.00	1.47	64.33
MP05	Woodlot	5.97	3.67	1.00	0.50	7.67	12.00	10.00	0.047	2.5	10.33	10.00	1.20	43.67
MP06	Woodlot	6.12	4.00	2.33	0.50	12.00	17.00	13.00	0.060	2.5	15.33	17.33	0.63	68.33
MP07	Woodlot	7.27	24.67	2.67	0.50	4.33	10.67	10.00	0.057	2.5	12.33	12.33	0.47	47.00

Table 7. (continued)

Parameter		Average Levels for Individual Parameters (Phos. - ppm)(Metals - mg/kg)												
		pH	Phos. (P2O5)	As	Cd	Co	Cr	Cu	Hg	Mo	Ni	Pb	Se	Zn
Max. Permissable Level in Sludged Soils		-	60	14	1.6	20	120	100	0.5	4	32	60	1.6	220
Site Identification														
MP08	Woodlot	6.93	9.67	1.67	0.50	2.50	18.33	10.00	0.077	2.5	10.00	11.33	0.73	34.67
MP09	Woodlot	5.35	20.33	2.00	0.50	2.67	10.00	10.00	0.052	2.5	10.00	10.00	0.97	35.67
Number of Sites		12	12	12	12	12	12	12	12	12	12	12	12	12
Mean Level		6.4	9.3	2.06	0.52	6.46	14.1	17.6	0.08	<2.5	12.1	14.8	1.09	56.0
Maximum Level		7.40	24.67	8.00	0.77	12.00	20.00	54.67	0.20	<2.5	19.33	23.67	1.93	108.00
Minimum Level		5.35	1.83	1.00	<0.5	<2.5	<10	<10	0.05	<2.5	<10	<10	0.47	24.67

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Table 8. Mean, Maximum, and Minimum Levels for All Parameters by Treatment

	Levels for Individual Parameters (Phos. - ppm) (Metals - mg/kg)												
Parameter	pH	Phos. (P2O5)	As	Cd	Co	Cr	Cu	Hg	Mo	Ni	Pb	Se	Zn
Treated Plots													
No. of Sites	36	36	36	36	36	36	36	36	36	36	36	35	35
Mean	7.1	29.4	2.21	0.54	6.95	18.5	21.6	0.08	<2.5	13.1	14.3	0.89	57.1
Maximum	7.87	89.00	6.67	0.83	16.00	55.00	58.67	0.22	<2.5	36.33	30.00	1.37	184.67
Minimum	5.47	5.00	1.00	<0.5	<2.5	<10	<10	0.03	<2.5	<10	<10	0.33	27.33
Non-Treated Plots													
No. of Sites	36	36	36	36	36	36	36	36	36	36	36	36	36
Mean	7.2	17.3	2.24	0.52	6.95	13.9	17.7	0.05	<2.5	12.6	13.9	0.85	57.5
Maximum	7.98	204.67	7.00	0.80	15.67	29.33	34.33	0.09	<2.5	24.33	32.67	1.53	225.00
Minimum	5.77	1.33	1.00	<0.5	<2.5	<10	<10	0.02	<2.5	<10	<10	0.30	<25
Woodlot Plots													
No. of Sites	12	12	12	12	12	12	12	12	12	12	12	12	12
Mean	6.4	9.3	2.06	0.52	6.46	14.1	17.6	0.08	<2.5	12.1	14.8	1.09	56.0
Maximum	7.40	24.67	8.00	0.77	12.00	20.00	54.67	0.20	<2.5	19.33	23.67	1.93	108.00
Minimum	5.35	1.83	1.00	<0.5	<2.5	<10	<10	0.05	<2.5	<10	<10	0.47	34.67

[1] Based on the average pH, phosphorus and heavy metal levels determined for the soils in each treatment at each site.

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Table 9. Summary of Number of Transect Samples and Analysis by Individual Parameter

Parameter	Number of Transects			MPL[1] (µg/g)	Maximum Level Tested[2]			No. of Transects with Level Higher than MPL			MDL[3] (µg/g)	No. of Transects with Level Lower than MDL		
	T[4]	NT[5]	W[6]		T	NT	W	T	NT	W		T	NT	W
pH	108	108	36	6	5.1	5.4	5.3	8	3	11				
Phosphorus	108	108	36	60	111	318	24	7	5	0				
As	108	108	36	14	7	7	9	0	0	0	0.5	0	0	0
Cd	108	108	36	1.6	0.9	0.9	1	0	0	0	0.5	89	92	29
Co	108	108	36	20	10	13	13	0	0	0	2.5	8	9	5
Cr	108	108	36	120	90	24	15	0	0	0	10	10	27	7
Cu	108	108	36	100	37	38	65	0	0	0	10	11	21	15
Hg	108	108	36	0.5	0.22	0.06	0.09	0	0	0	0.01	0	0	0
Mo	108	108	36	4	<2.5	<2.5	<2.5	0	0	0	2.5	108	108	36
Ni	108	108	36	32	85	31	16	1	0	0	10	39	51	17
Pb	108	108	36	60	45	39	28	0	0	0	10	26	38	6
Se	108	108	36	1.6	2	1.7	2	1	1	3	0.25	0	0	0
Zn	108	108	36	220	227	246	130	1	2	0	25	1	6	0

[1] MPL = Maximum Permissible Level in sludged soils as reported in the current guidelines.
[2] Permissible level for pH is 6.0. pH levels below 6.0 were considered above maximum.
[3] MDL = Method Detection Limit
[4] T = Treated
[5] NT = Non-treated
[6] W = Woodlot

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Figure 1. Locations of the Sampled Sites

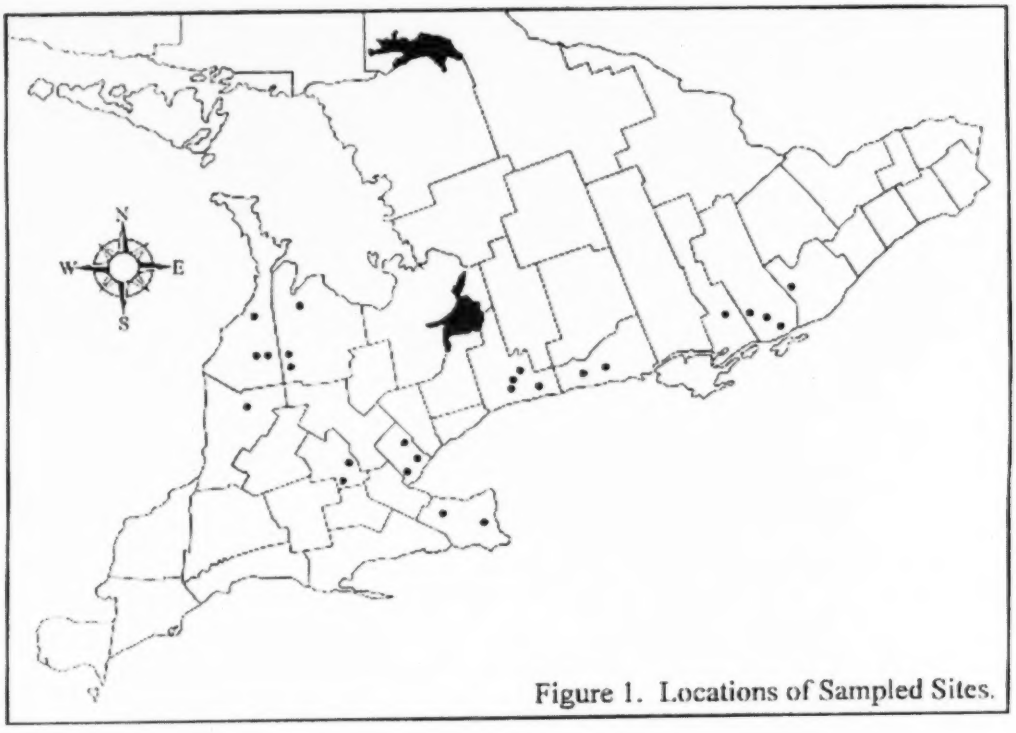

Figure 1. Locations of Sampled Sites.

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